# C4I Community of Interest C2 Roadmap

## 24 March 2015

## John Willison (SES), C4I COI Lead

# Agenda

- **Purpose**

- **C2 Roadmap Approach**

- **C2 Roadmap Conclusion**

- **Current C4I COI Focus Areas**

- **Conclusion**

# C4I COI Overview

- Purpose: The C4I CoI provides the DoD S&T EXCOM recommendations on matters related to planning and managing research and development programs in the fields of Command, Control, Communications, Computers, & Intelligence

- Initial task is to develop a C2 Roadmap

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# C4I COI Approach

- As chartered, initial focus of C4I COI is on C2

- C2 capability advancements over time result from the application of combinations of advancements made in different technology areas applied to C2 domain

- Task is relatively complex given:
  - Inter-dependency between C4I and all other COIs
  - Many-to-many relationship of technology advancements to capability area advancements (C2 and other)
  - Similar technology advancements often enable different C2 advancements in order to address unique, Service-specific needs
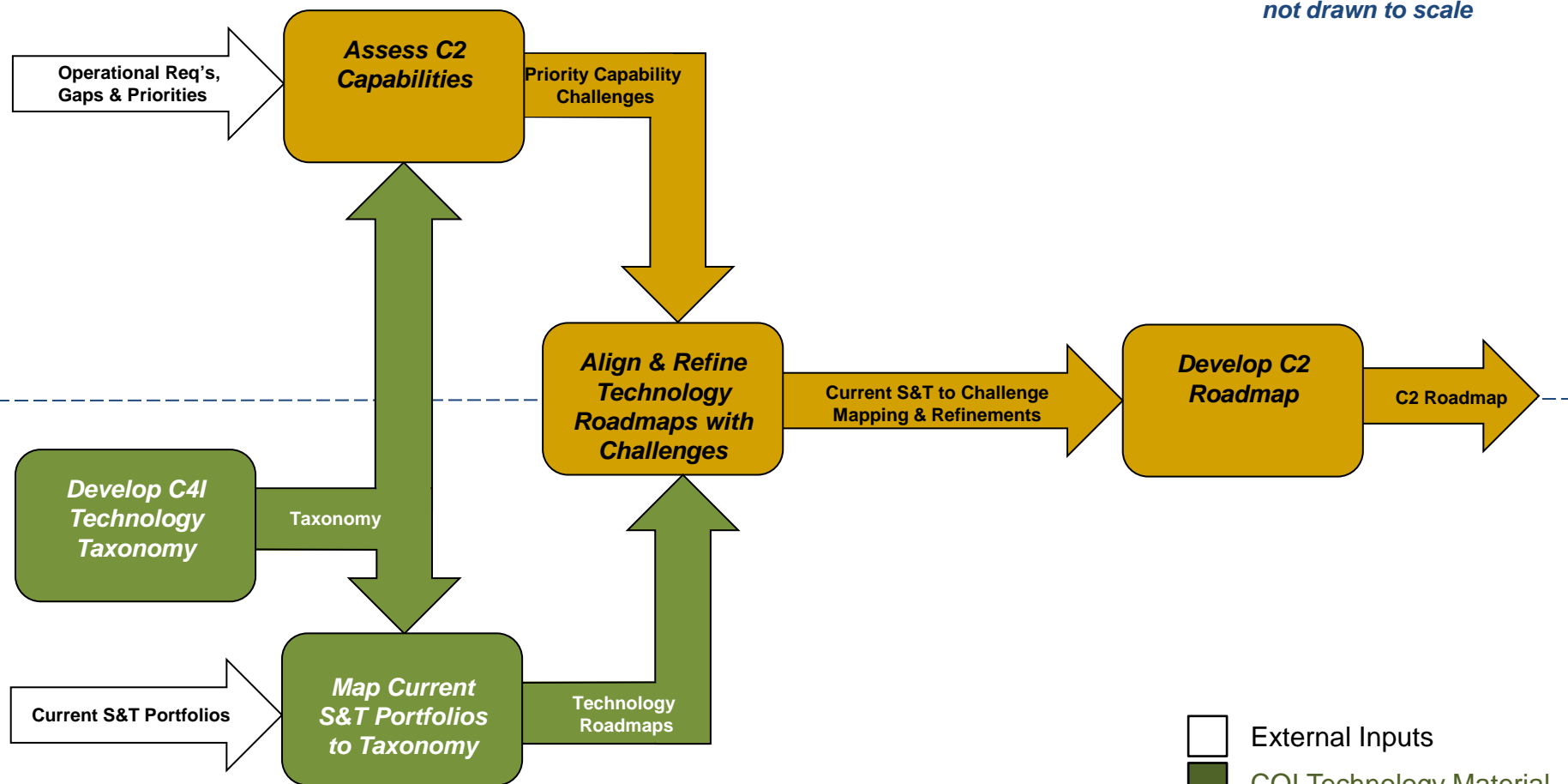
# C2 Roadmap Approach
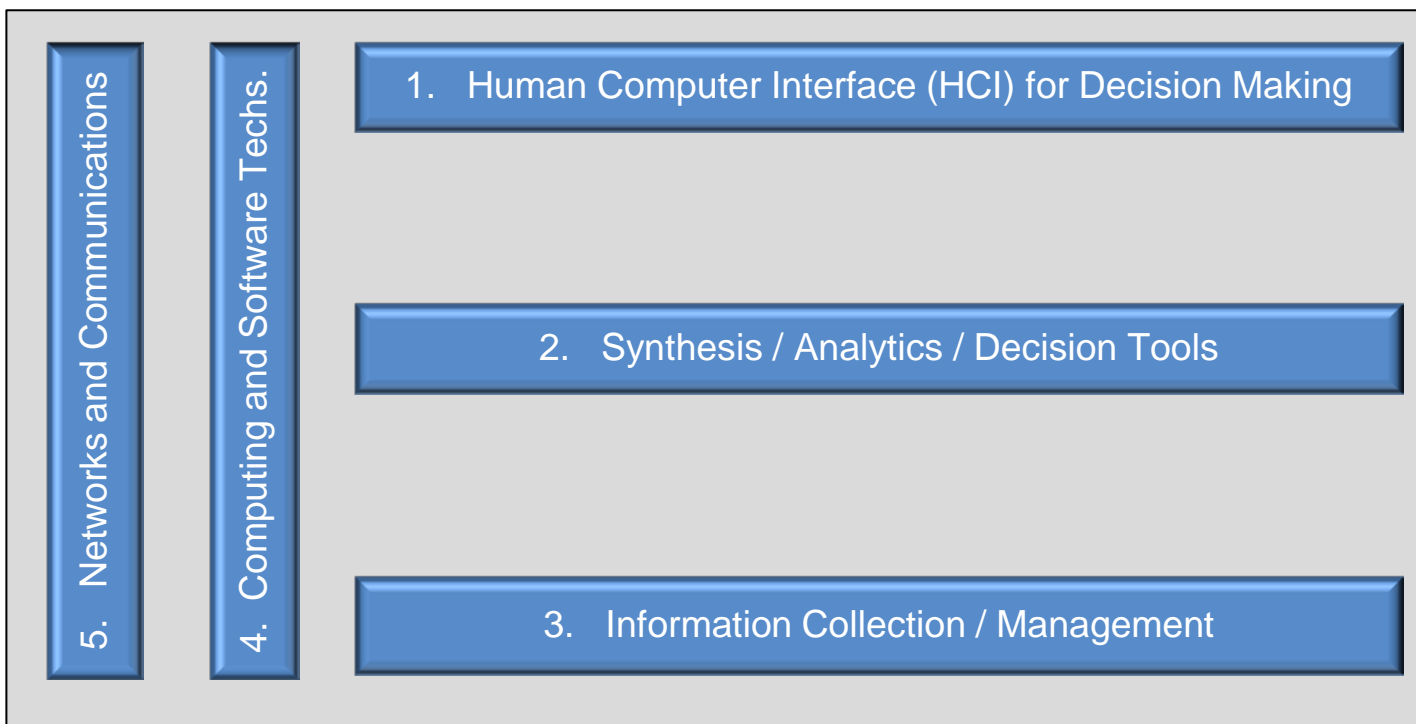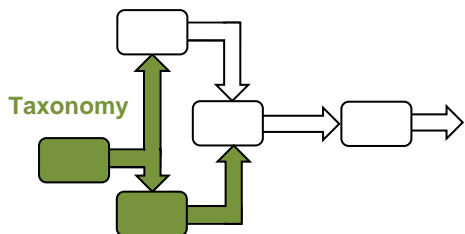## - Revised -

**Capabilities…What do we need?**

*Note - Process (over)simplified and not drawn to scale*



Operational Req's, Gaps & Priorities → **Assess C2 Capabilities**

Priority Capability Challenges

**Align & Refine Technology Roadmaps with Challenges**

Current S&T to Challenge Mapping & Refinements → **Develop C2 Roadmap** → C2 Roadmap

**Develop C4I Technology Taxonomy** — Taxonomy

Current S&T Portfolios → **Map Current S&T Portfolios to Taxonomy** — Technology Roadmaps

**Technologies…What can we get?**

Legend:
- External Inputs
- COI Technology Material
- COI Capability Material

# Technology Taxonomy
# Tier 1

**Taxonomy**

1. Human Computer Interface (HCI) for Decision Making

2. Synthesis / Analytics / Decision Tools

3. Information Collection / Management

5. Networks and Communications

4. Computing and Software Techs.

# Technology Taxonomy: Tier 2

## HCI for Decision Making

- User Interaction
- Collaboration
- Information Presentation
- Display Management

## Synthesis / Analysis / Decision Tools

- Sensor Understanding
- Data Fusion and Analysis
- Human Language Technology (HLT)
- Mixed Initiative Planning and Execution
- Autonomous Reasoning and Decision Making
- Continuous Assessment

## Information Collection / Management

- Acquire
- Transform
- Access
- Architectures

## Computing and Software Technologies

- Computing Hardware
- Algorithms and Software
- Systems and Processes

## Networks and Communications

- Radios and Apertures
- Networks
- Information

# Technology Taxonomy: Tier 2&3

## HCI for Decision Making

- User Interaction
  - Understanding Nonverbal Behavior
  - Natural Task & Content Interaction
  - Bio-Psychometrics
- Collaboration
  - Facilitated Shared Awareness
  - Virtual Human Behavior Modeling
  - Collaboration with autonomous systems (Advanced Supervisory Control)
- Information Presentation
  - Innovative Display Technologies
  - Presentation Aware Information Derivatives
  - Task/Decision based Information Abstraction
- Display Management
  - Task & Display-Aware Information Routing
  - Task & Display Sensitive Adaptive Information Displays
  - Progressive Information Disclosure
  - Spatial Localization Cueing
  - Adaptive Aesthetics

## Synthesis / Analysis / Decision Tools

- Sensor Understanding
  - Object/Anomaly Detection
  - Object Tracking
  - Object/Attribute Recognition Mission assurance
  - Scene Reconstruction / Understanding
- Data Fusion and Analysis
  - Data Conditioning
  - Object / Entity Assessment
  - Situation Assessment
  - Impact Assessment:
  - Process Refinement/Resource Management
- Human Language Technology (HLT)
  - Textual Data Analysis
  - Speech Analysis
- Mixed Initiative Planning and Execution
  - Cognitive Work Analysis
  - Course of Action Development and Analysis
  - Synchronization of cross domain (air, space, cyber, land and maritime) effects
  - Dynamic re-allocation and tasking
  - Distributed collaboration
- Autonomous Reasoning and Decision Making
  - Machine Learning
  - Cooperative Teaming
  - Automated Planning and Plan Recognition
  - Closed loop Resource Management
  - Trust
- Continuous Assessment
  - Presentation of forces
  - Operational assessment
  - Mission Assurance
  - Managing Uncertainty

## Information Collection / Management

- Acquire
  - Adaptive Collection
  - Aggregation & Inference
- Transform
  - Unstructured-to-structured (rep & process)
  - Ontologies
  - Provenance
- Access
  - Search & Retrieval
  - Info Discovery
  - Trust & Access Control
- Architectures
  - Tactical Realization of Enterprise Architectures
  - Policy-based Information Exchange
  - Heterogeneous Interoperability
  - Semantic Stores and Warehouses

## Computing and Software Technologies

- Computing Hardware
  - High Performance Computing
  - Distributed Tactical Computing
  - Advanced Computing Architectures
  - Advanced memory and Storage Technologies
- Algorithms and Software
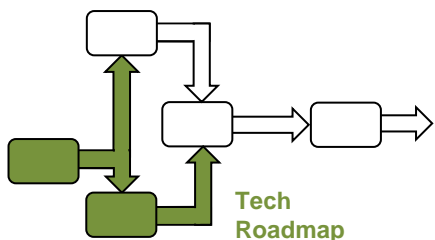  - Programming Languages
  - Formal Methods
  - Parallel OS / scalable algorithms
  - Predictive science
  - Uncertainty Quantification
  - Optimization / Intelligent Algorithms
  - Data Intensive Science algorithms
- Systems and Processes
  - Co-design and user composition
  - Software Engineering
  - Software architectures
  - Energy-efficient (systems/processors)
  - Intelligent/Adaptive computing platform
  - Simulation and Emulation processes
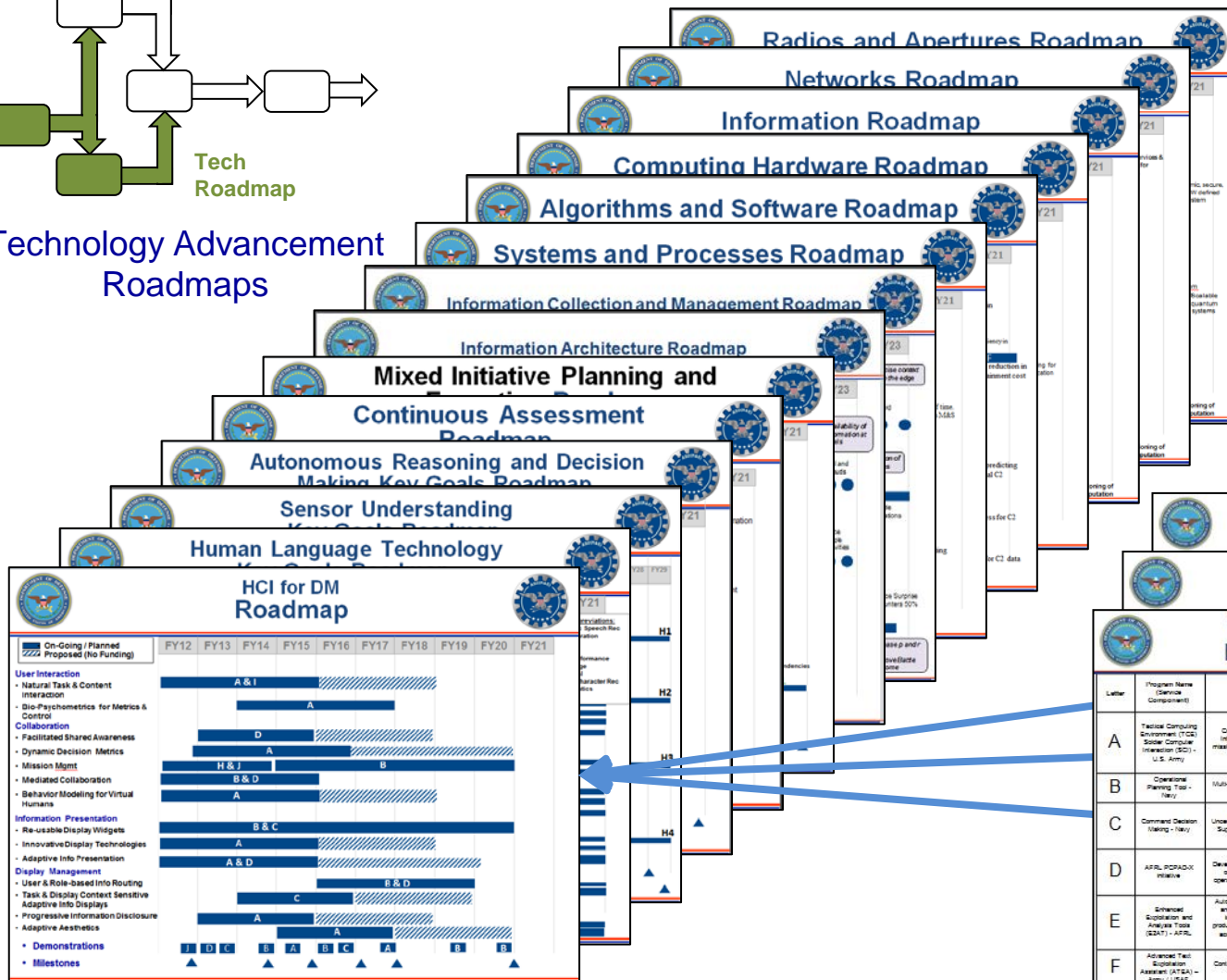
## Networks and Communications

- Radios and Apertures
  - Spectrum sensing/sharing/management
  - Unicast/Multi-cast protocols
  - Software defined interfaces
  - Dynamic Forward Error Correction (FEC)
  - Spatial multiplexing
  - Quantum, optical, THz communications
  - Physical layer security
  - Components
  - Compatible or common gateways/interfaces
- Networks
  - Software-defined/cognitive networking
  - Network coding
  - Routing protocols
  - Transport protocols (e.g. IP)
  - Disruption tolerant networking
  - Directional networking
  - Network assurance
  - Dynamic collaboration
- Battlespace Networked C2
  - Transport protocols/services/applications
  - Data/message standards
  - On-demand QoS-based services
  - Digital policy-based prioritization
  - Dynamic bandwidth allocation
  - Automated network management

# Technology Roadmap Summary



**Technology Advancement Roadmaps**
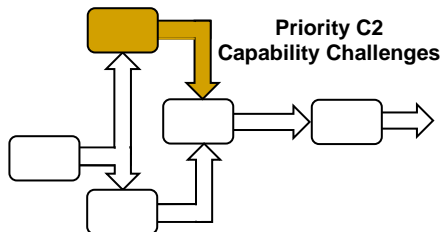
Tech Roadmap

*Over 350 pages of material*

Programs and metrics

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# C2 Definition, Vision, & Gaps

**Priority C2 Capability Challenges**

## Joint C2 Vision

- Commanders and staff require Joint C2 capabilities that provide timely, relevant and accurate data to **improve their situational awareness** and **assist decision-making**.

## Joint C2 Definition

- **Command and Control**
  - "The exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of the mission. Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities, and procedures employed by a commander in planning, directing, coordinating, and controlling forces and operations in the accomplishment of the mission. Mission command is the preferred method of exercising C2."

- **Mission Command**
  - "The conduct of military operations through decentralized execution based upon mission-type orders. Empowers individuals to exercise judgment in how they carry out their assigned tasks... Successful mission command demands that subordinate leaders at all echelons exercise disciplined initiative and act aggressively and independently to accomplish the mission. Essential to mission command is the thorough understanding of the commander's intent... and a command climate of mutual trust and understanding."

-Joint Publication 1 – Doctrine for the Armed Forces of the United States, 25 March 2013

FOUO: Pre-decisional

## AF C2 Capability Gaps 2

## AF C2 Capability Gaps 1

CFLI: ACC

## Navy C2 Gaps

## Army Mission Command Gaps

| Objective | Taxonomy | Sources |
|---|---|---|

## Joint C2 Capability Gaps

- **Gap 1:** Inability to **collaboratively construct and actively manage operations plans** and orders
- **Gap 2:** Inability to manage **creation and updating of SA**
- **Gap 3:** Inability to **collaboratively plan and synchronize** employment of forces
- **Gap 4:** Inability to make releasable **COP track information available** and accessible to mission partners of separate network domains.
- **Gap 5:** Inability to quickly and securely **pass non-COP operations and planning information** to mission partners on separate networks
- **Gap 6:** Inability to provide **integrated, interoperable, Joint C2 information environment**
- **Gap 7:** Inability to **integrate ISR** assets across national, Service and Component boundaries

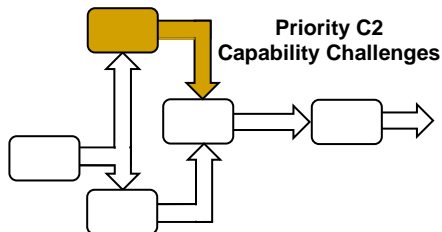Joint Command and Control (C2) Capability Development Document (CDD) Version 1.4 9 April 2013

FOUO: Pre-decisional

References:
- Joint Pub. 1: Doctrine for the Armed Forces of the United States
- Joint Command and Control (C2) Capability Development Document (CDD) Version 1.4

# Priority C2 Capability Challenges
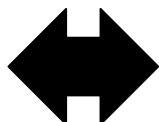
**Priority C2 Capability Challenges**

## Priority C2 Capability Challenges

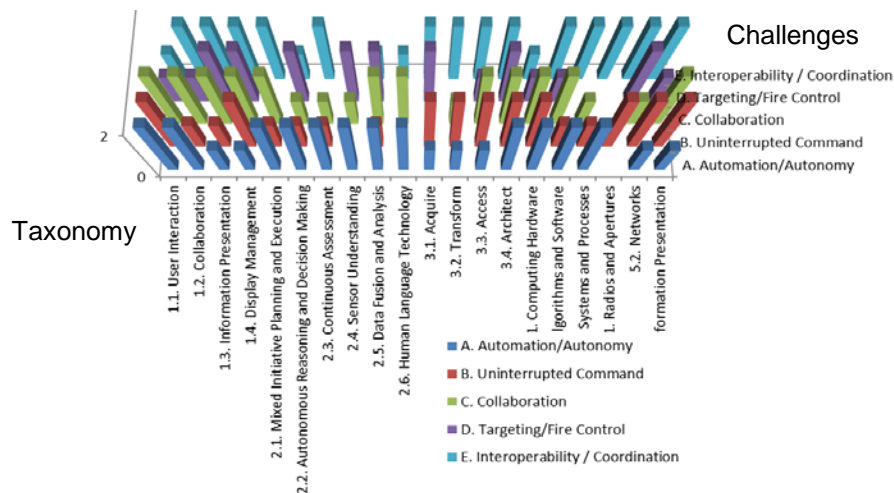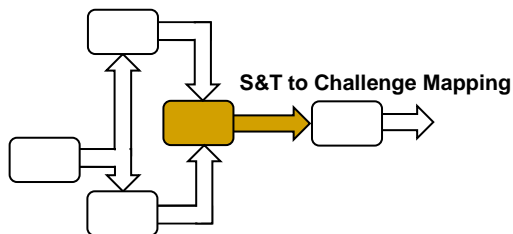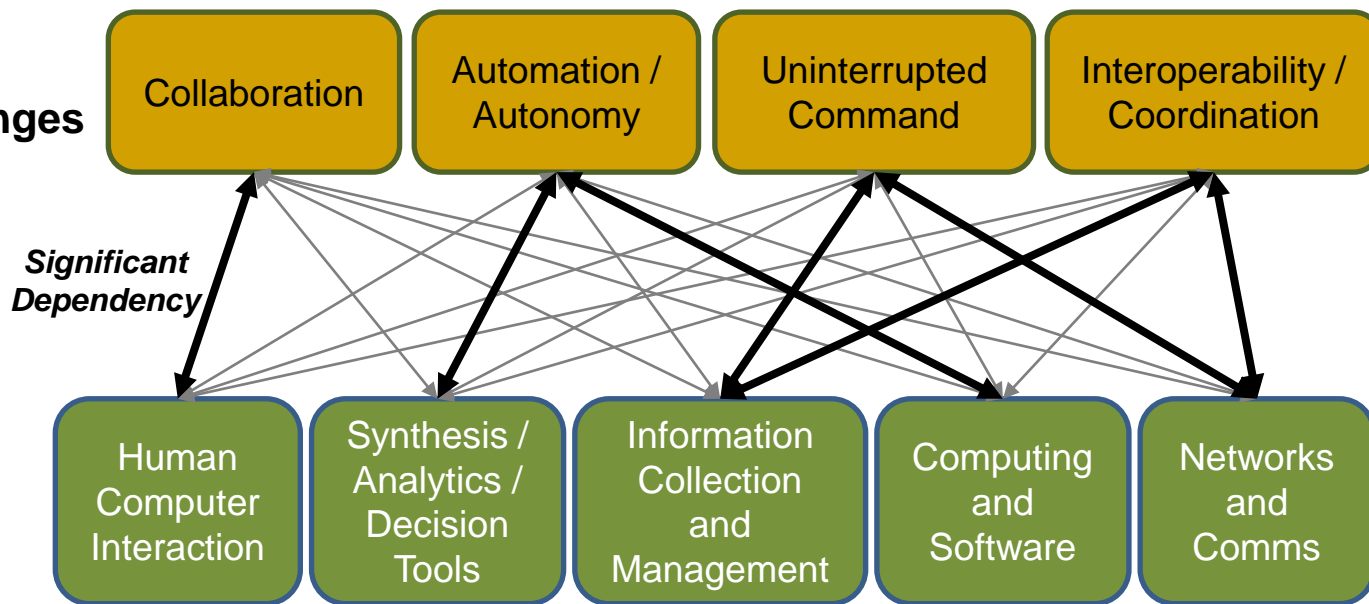| | |
|---|---|
| **Collaboration** | Enable human interaction and collaborative decision making to achieve unity of effort |
| **Automation / Autonomy** | Enhance force capability through Automation/Autonomy |
| **Uninterrupted Command** | Enable mission execution at all echelons anywhere, at anytime, regardless of network/system status |
| **Interoperability / Coordination** | Seamless and secure movement and integration of mixed format data/information between service, joint and coalition networks/systems |

## C2 Capabilities
(MAPE / MC / OODA)
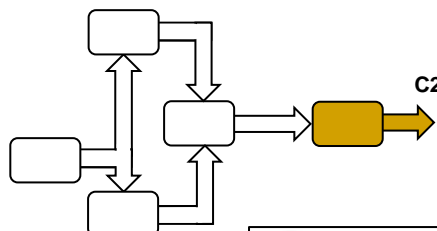
- Monitor / Understand / Observe
- Assess / Visualize / Orient
- Plan / Describe / Decide
- Execute, Monitor/ Direct / Act

# Technology to Capability Mapping



**S&T to Challenge Mapping**

**Challenges**
- E. Interoperability / Coordination
- D. Targeting/Fire Control
- C. Collaboration
- B. Uninterrupted Command
- A. Automation/Autonomy

**Taxonomy**

- ■ A. Automation/Autonomy
- ■ B. Uninterrupted Command
- ■ C. Collaboration
- ■ D. Targeting/Fire Control
- ■ E. Interoperability / Coordination

**Priority C2 Capability Challenges**

| Collaboration | Automation / Autonomy | Uninterrupted Command | Interoperability / Coordination |

*Significant Dependency*

**Technologies**

| Human Computer Interaction | Synthesis / Analytics / Decision Tools | Information Collection and Management | Computing and Software | Networks and Comms |

# C2 Capability Roadmaps

**C2 Roadmaps**

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# C2 Capability Roadmaps
## - Top Level -

| C2 Priority Challenges | Barriers/Impacts | Enabling S&T Investments |
|---|---|---|
| **Uninterrupted C2**<br>• Operate in A2/AD Environment<br>   -Maintain Connectivity<br>   -Operate Disconnected<br>• C2 in Austere Environments<br>• C2 On The Move | • Network vulnerabilities<br>• Overdependence, no fallback | **Near**: Mobile computing platforms, Discovery algorithms, Study alternative transmission platforms<br>**Mid**: Mission aware prioritization, cognitive reconfiguration<br>**Far**: Non-contiguous spectrum, Hardened/advanced transmission media (quantum, optical) |
| **Autonomy/Automation**<br>• Machine "Comprehension" of CDR's Intent<br>• Lighten the staff's load<br>• Improve Decision Making | • Overwhelming data abundance<br>• Human resources | **Near**: Planning/COA Analysis, autonomous interpretation of intent, better understanding of trust<br>**Mid**: Real-time planning updates, Certainty metrics in support of recommendations/actions, V&V in support of trust<br>**Far**: Staff support in absence of staff, near real-time planning updates, comprehend orders documents |
| **Collaboration**<br>• Capture CDR's Intent<br>• Intuitive<br>   -Product Sharing<br>   -Interaction | • Communicate but can't share ideas<br>• Unintuitive interface | **Near**: Touch, gesture, voice interaction, improve understanding of distributed decision making, tailorable visualization<br>**Mid**: Automated/user-sensing display management, Human Machine Experimentation Environment,<br>**Far**: decomposed representation of commander's intent, transparent facilitated collaboration, context/user aware information display |
| **Interoperability/Coordination**<br>• Cross Domain Solutions<br>• Cognitive Systems | • Partners left in dark<br>• Dependence on Field Support Reps. | **Near**: push/pull info mechanisms, scalable waveforms, language translation, exploration of data/info sources<br>**Mid**: unified, cross domain platform solutions, reduce unstructured data exchange, unstructured data transformation<br>**Far**: real-time spectrum management, information sharing across waveforms and message standards, automatic info guard functions |

**Blue text indicates tie with human-machine initiative**

# HCI for Decision Making Challenges

**Challenge:** Speed of Command requires timely delivery of useful information, to the right people at the right time, presented so as to support mission critical decisions. Too much data - not enough information.

## Opportunities:

- Valuing & sharing information based on task needs [HCI-1]

- Uncertainty Management [HCI-3]

- Proactive Planning Decision Support, Learn User's habits / needs [HCI-5]

- Information Provenance Pedigree [HCI-6]

- Machine Facilitated Collaboration for managing Autonomous & Complex Systems [HCI-8]

- Information Management for limited connectivity [HCI-11]

- User Behavioral Anomaly Detection [HCI-13]

# Synthesis/Analytics/Decision Tools Challenges

**Challenge:** Current C2 planning processes exhibit horizontal and vertical information gaps, and human planners lack cognitive bandwidth to effectively coordinate and synchronize operations across the unique complexities of the air, space, cyber, land and maritime domains.

## Opportunities:

- Develop tools for tracking, positive ID, observing behaviors and activities of objects in all domains to determine adversary threats [SADT-1]

- Determine the nature and impact of conditions and events on force capabilities and commander's intent [SADT-2]

- Develop tools for developing, evaluating, and selecting courses of action[SADT-3]

- Develop technologies for synchronization of forces, and real-time planning updates [SADT-4]

# Information Collection/ Management Challenges

**Challenge:** Recent conflicts indicate we must consistently prepare for operations in contested environments that are communications constrained and demand increased op tempo and exploitation of heterogeneous sources, all in an era of decreasing manpower

**Opportunities:**

- Scalable semantic interoperability [ICM-1]

- Tactically distributed collection & processing [ICM-2]

- Task-centric, federated, extensible data models [ICM-3]

- Context enhanced information fusion and integration [ICM-5]

- Dynamic context (mission/user) aware information retrieval [ICM-6]

# Computing and Software Challenges

## Challenges:

Rapid obsolescence hinders maintenance of overmatch, consumer systems enable opportunities to challenge our overmatch. Disruptive technologies such as quantum, bio-mimicking, and other new architectures present opportunities and threats.

## Opportunities:

- Cost of Tech Refresh: Improve Reconfigurability, Modularity, Interoperability, Extensibility
- Robust real-time situational awareness for C2 by exploiting computing research and software technologies
- Future and exotic computing architectures and associated algorithms and software
- Distributed Computing
- Reduce Size, Weight, Power, Cost

# Networks and Comms Challenges

**Challenge:** An increasingly crowded spectrum and contested environments threaten our ability to assure connectivity for C2

## Opportunities:

- Spectral Efficiency [NC-1]
- Spectral Diversity [NC-1]
- Electronic Protection (Anti-Jam Comms & Co-Site Mitigation) [NC-3]
- LPD/LPI Comms [NC-4]
- Increased Range [NC-7]
- Increased Loss Tolerance & Recovery [NC-7]
- Mobile Ad Hoc Networking [NC-8]
- Autonomous Network Management & Control [NC-10]

# Collaboration Opportunities

## Warfighter Capability:

- Ability for CDR, staff and peers to seamlessly interact and collaborate using digital data across mission areas in real time in distributed environments

## Opportunities:

- Develop standards and employment protocols for User Defined Operational Picture widgets & services across multiple missions and warfare domains
- Develop agent-based simulations of military C2 units for evaluation of alternative HCI design concepts
- Develop Context Driven Decision Making capabilities
- Research languages and techniques for developing executable policies that can be potentially be applied to multi-security-domain exchange
- Develop enterprise network collaboration tools and collaboration apps for application to military needs

# Autonomy Opportunities

**<u>Warfighter Capabilities:</u>**

- Ability to automate work that contributes to increasing speed and effectiveness of C2.

- Supervisory control of multiple autonomous systems

**<u>Opportunities:</u>**

- Research human trust in agent-presented information and analysis and in autonomous systems

- Develop a testbed and evaluate various advanced Human Computer Interface (HCI) technologies that allow Commanders to task and evaluate  autonomous C2 systems

- Develop scenario based experiments to measure military effectiveness and highlight that autonomous operations can be trusted to perform missions as defined.

- Develop realistic C2 of autonomous systems challenge problems that are motivated by operational experience and evolving mission needs

# Automation Opportunities

**Warfighter Capabilities:**

- Human-machine teaming for faster, informed decision making.
- Development and analysis operational plans and courses of action Maximized operator efficiency, give the machine jobs the machine does better

**Opportunities:**

- Translation of  commanders intent and OPORDS to machine readable format
- Identify the biggest payoff C2 capabilities to leverage autonomy and automation to focus investments, [which manual processes could be done faster and better]*
- Develop capabilities for diverse genre networks (social, information, communication) information fusion.
- Adapted COTs and GOTs to move from traditional computing architectures to emerging and innovative computing architectures specifically for C2 applications

# Uninterrupted Command Opportunities

**Warfighter Capability:**

- Enable mission execution at all echelons anywhere, at anytime, regardless of network/system status

**Opportunities:**

- Model and demonstrate technology alternatives for provisioning and operating assured communications in DIL and A2/AD joint space, aerial layer, surface and undersea environments.

- Develop cross-service, mission-adaptive collection and processing algorithms that can be employed at the sensor level to insure mission critical data collections have highest priority and distribution requirements are minimized.

- Research multi-layer distributed C3 capabilities to enable centralized planning, distributed control, and decentralized execution.

- Develop resource-aware information distribution algorithms that can be employed to decrease data throughput requirements when connectivity is intermittent.

- Mature neuromorphic, cognitive and quantum computing similar to traditional computing field

# Interoperability/Coordination Opportunities

## Warfighter Capabilities:

- Ability to seamlessly and securely move and integrate mixed format data/information between service, joint and coalition networks/systems in DIL Environments

- Ability for forces to enter/exit any operational environment and maintain secure connectivity to the grid, communicating at will with their mission partners, and having continuous access to relevant data under any threat conditions

## Opportunities:

- Develop and utilize standards and protocols for interoperability of data, standardization approaches to SDK and apps across Services

- Investigate cognitive and software defined networking approaches as affordable means to interoperability, and to shape formative, pending standards developments.

- Extend Enterprise Cloud concepts to tactical environment for cross-service Situation Awareness applications

- Evaluate the impact of trust, quality and value mechanisms for addressing cross-service network overload and mission outcome.

# Opportunities for Industry Engagement

- **Innovation Marketplace: http://www.defenseinnovationmarketplace.mil/**
- **C4I Page Under Development**
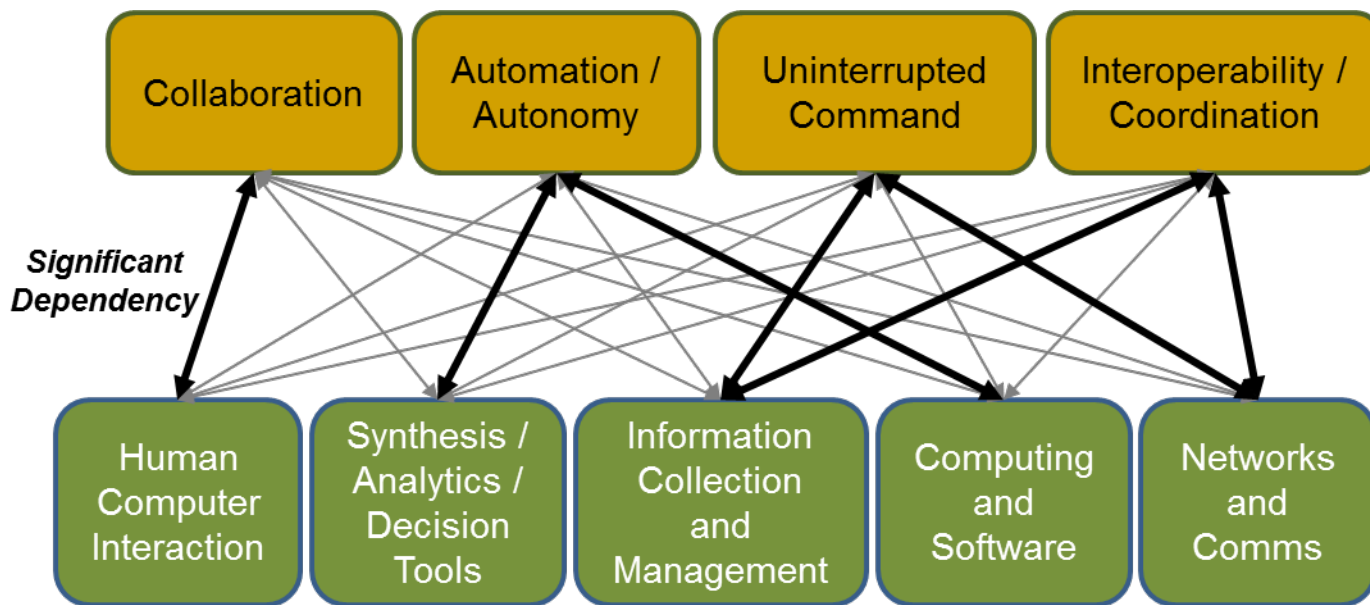
# C2 Roadmap Conclusions

COI activity provided for:

- **Common taxonomy and process for Joint S&T community collaboration on C2 and C4I**

- **Consensus on Priority C2 Capability Challenges that provided scope and focus for continued collaboration**

- **Refinement and completion of mid-term and long-term C2 Roadmaps**

# C4I COI Current Focus

- **"Uninterrupted D2D"**

- **Human-Agent Planning Teaming and Execution (HAPTE)**

- **Exploring Other Cross-COI Opportunities**

# C4I COI Conclusions

- **'Uninterrupted D2D' being pursued as a follow-on COI activity**
  - Foundational to C2
  - Concluded independently from parallel 'Hard Problems' findings
  - Assured Position, Navigation, and Timing (PNT) and Comms included within scope of this activity; applying the same COI process to these areas

**Stay Connected**

**Operate Disconnected**

Distributed Collection and Processing — Mobile Ad Hoc Net

Spectral Diversity — Cognitive Radio/Network Management — Electronic Protection

Uncertainty Management — Improved Loss Tolerance

Information Management/Caching

Self Contained Timing/Navigation — Future Computing Architectures?

Machine Readable Commander's Intent

Rules of Engagement

# Cross-COI Conclusions

- **Human-Agent Planning, Teaming and Execution (HAPTE) Cross COI Intiative**
  - Explicit touch points in taxonomies across C4I, Human Systems, Autonomy, and Sensors COIs
  - Potential to expand collaboration beyond existing and established communities of practice
  - Most significant advancement opportunity exists at the intersection of shared interests and investments

  *Propose this area as the basis for follow-on OSD focus and support*

# Human-Agent Planning, Teaming and Execution (HAPTE) Initiative

## Objectives:

- **develop machine capability to capture and intelligently interpret Commander's Intent**
- **demonstrate improved Commander's mission analysis, Course of Action development / assessment**
- **demonstration of multi-agent development and execution of Joint ISR plans**

## Operational Impact:

- **increase the speed and accuracy of Commander and staff decision making**
- **increase mission effectiveness**
- **reduce manpower requirements**

| | |
|---|---|
| •**System Interfaces**<br>•Personnel & Training<br>•Social & cultural Understanding<br>•Protection & Sustainment | **Human Systems COI** |
| •**HCI for Decision Making**<br>•**Synthesis, Analytics for Decision Making**<br>•**Information Collection & Management**<br>•**Computing and SW**<br>•Networks and Communications | **C4I COI** |
| •**Human Autonomous Sys. Interaction & Collab.**<br>•Scalable Teaming of Autonomous Systems<br>•**Machine Perception, Reasoning & Intel**<br>•T&E, V&V | **Autonomy COI** |
| •Electro-Optical and Infrared<br>•Acoustic, Seismic and Magnetic<br>•Radio Frequency (Radar)<br>•**(Processing)** | **Sensors COI** |

*HAPTE will be executed leveraging expertise from across the Services and the Communities of Interest. Partners include: ARL, ARI, RDECOM, NRL, ONR and AFRL.*
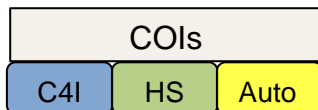
# HAPTE

**5. Manned/unmanned agents execute ISR plan and feed information to commander**

Information Presentation, Presentation Aware Information Derivatives, Task/Decision based Information Abstraction, Collection Management

Human-Machine Teaming, Intuitive Interaction

Robust Self-organization, Adaptation, & Collaboration, Calibrated Trust, Understanding the Situation/Environment

**4. HAPTE systems task team of manned/unmanned agents to execute joint ISR plan**

Intelligent Planning tools, Interoperability

Decentralized Mission-level Task Allocation/Assignment, Robust Self-organization Adaptation & Collaboration, Human-Agent Interaction

**3. Based on intent & assets, intelligent systems assist in developing joint-ISR plan**

Synthesis/Analytics/Decision Tools, COA development & Analysis, Collaboration with Autonomous Systems, Natural Task & Content Interaction, Situation Assessment

Intelligent, Adaptive Aiding

Understanding the Situation/ Environment

**2. HAPTE systems interprets intent**

Collaboration with Autonomous Systems

Learning and Reasoning, Human-Agent Interaction, Common Understanding & Shared Perception

**1. CDR issues mission intent in machine readable format**

User Interaction, Natural Task & Content Interaction, Plan Recognition, Human Language Technology

Intuitive Interaction, Human-Machine Teaming

# Conclusion

- **C2 Roadmap Baselined**

- **Follow-on Activities**

    – Continue to Refine C2 Roadmap

    – Work "Uninterrupted D2D"

    – Look for Cross-COI Opportunities

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